Research on the Distribution of superconducting currents in Parallel Circuits

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Abstract

In this research a measurement device is designed capable of measuring the distribution of superconducting currents in parallel circuit. Hall effect sensors are used to measure the magnetic field excited by the current to determine the intensity of the current. The measurement results indicate that the distribution of superconducting current in parallel circuits is inversely proportional to the self-inductance of the branch circuits.

Keyword: superconductivity, hall sensor, parallel circuit, cuprate superconductors

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1 Introduction

Since the discovery of superconductivity by H. K. Onnes [1] in 1911, superconductivity research has been a hot topic in physics. Progress has been made in the search for new superconductors, such as copper oxide superconductors[2], iron-based superconductors[3], and nickel-based superconductors[4]. Superconducting currents exhibit many novel properties different from normal state currents. In 1933, W. Meissner and R. Ochsenfeld[5] discovered the perfect diamagnetism of superconductors. In 1950, F. London [6] pointed out that the behavior of electrons in superconductors is a sign of collective motion. L. N. Cooper[7] proposed in 1956 that superconducting carriers are two electrons bound together in the form of Cooper pairs. Cooper pairs are equivalent to bosons, and a large number of Cooper pairs form a Bose-Einstein condensation at low temperatures, exhibiting collective motion behavior, so superconducting current is a macroscopic quantum phenomenon. According to the Ginzburg-Landau[8] equation, the superconducting current is distributed on the surface of the superconductor. It is commonly known that there are significant differences in the transmission properties between superconducting and normal state currents.

In this study, an experimental device was designed to measure the distribution of current in parallel circuit formed by superconductors, and the rule governing the distribution of superconducting currents in parallel circuits is discussed.

2 Experimental preparation

2.1 Experimental principle

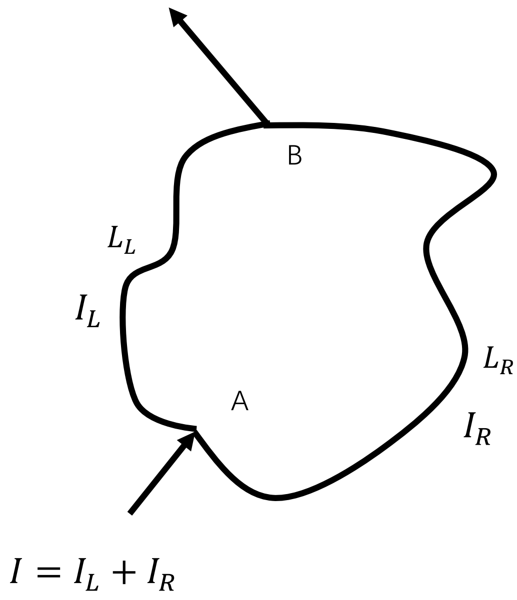

Fig.1. A parallel circuit composed of superconductors。 L_L and L_R are of self-inductance of the left and the right branches.

A parallel circuit formed by superconductor is shown in Figure 1, and the self-inductance of the two branches are L_L and L_R, respectively. If there is a current flowing through the parallel circuit, splitting to I_L and I_R between two branches. The variation of magnetic flux generated by the currents I_L and I_R in the closed loop is $\Delta\Phi = L_L * I_L - L_R * I_R$. By the electrodynamics of the superconductivity, the magnetic flux of the closed superconducting circuit is conserved, i.e., $\Delta\Phi = 0$, from which I_L/I_R=L_R/L_L[9] . The distribution of superconducting currents in parallel circuits is proportional to the inverse ratio of their self-inductance.

In this paper, the rule I_L/I_R=L_R/L_L for distribution of superconducting current in the parallel circuits will be confirmed experimentally.

2.2 Preparation of samples

According to the composition of $YBa_2Cu_3O_{7-\delta}$, a total of 40 grams of Y_2O_3 , $BaCO_3$ and CuO raw materials were weighed, fully mixed, calcined at a temperature of 1133K for 20 hours, then took out and ground into powders, two discs with a mass of 15 grams each and a diameter of 40 mm were pressed out, and then sintered at 1203K for 20 hours, took out after cooling, and processed to two samples with dimensions as shown in Figure 2.

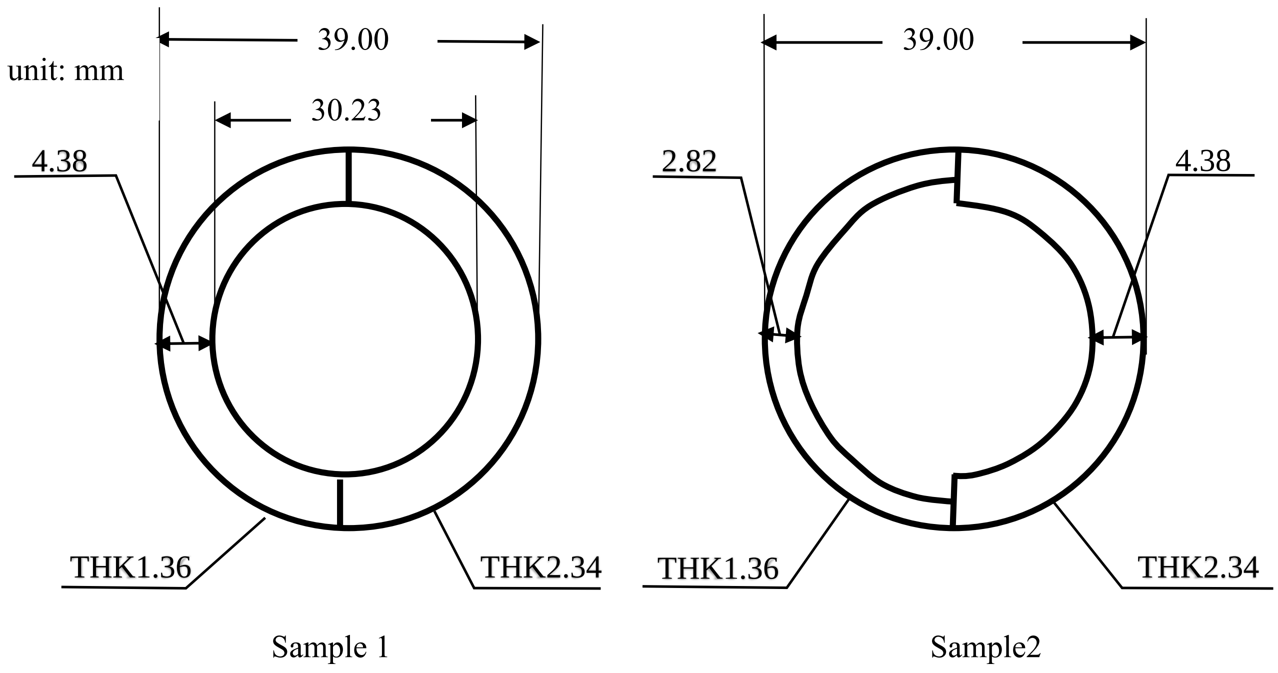

Fig.2. Shape and size of the samples. THK denotes thickness

For both samples the thickness of the left semicircle is 1.36 mm and the right semicircle is 2.34 mm. Sample 1 has a loop width of 4.38 mm. For sample 2 the loop width on the left semicircle is 2.82 mm, and the right semicircle is 4.38 mm.

2.3 Installation of samples

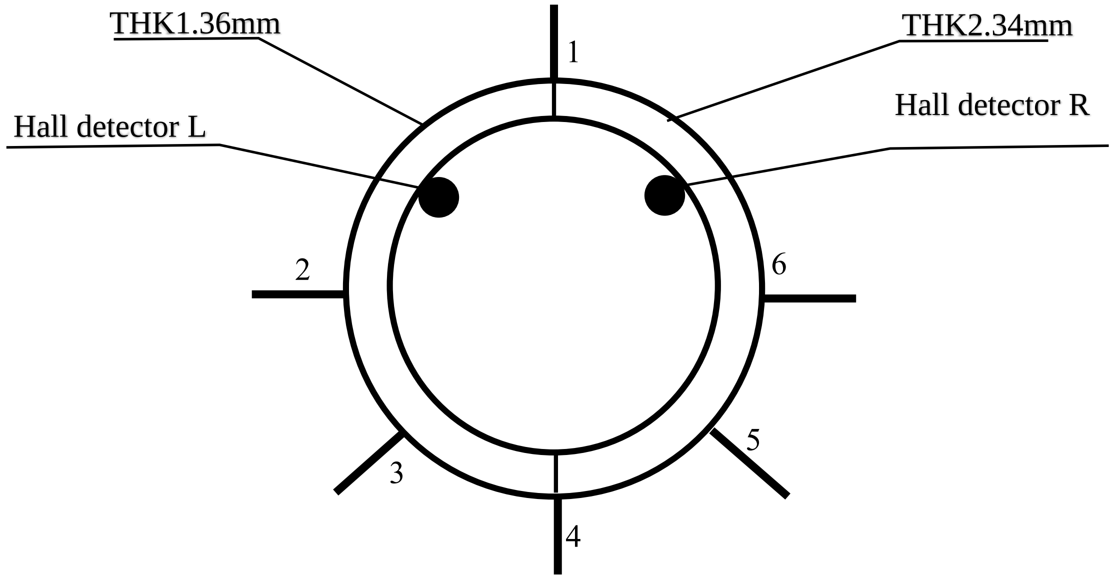

Fig.3. Sketch of sample installation。

The installation of sample is shown in Figure 3, with 6 electrodes and 2 Hall detectors evenly spaced around the loop circuit. Hall detectors are used to measure the magnetic field excited by the current, so the intensity of the current can be determined by the Hall voltages.

Installed as in Fig.3. for both samples 1 and 2 the thickness of the left semicircle is 1.36 mm and of the right is 2.34 mm. Electrode 1 is the fixed current i/o terminal, and another terminal can be switched to electrodes 2, 3, 4, 5, and 6 respectively.

2.4 Calculation of self-inductance

L_R/L_L can be calculated based on the position of the electrode and shape of circuits. The sample was installed as shown in Figure 3. The left semicircle and the right semicircle are uniform by themselves. Let the self-inductance of the unit length in the left semicircle is k_L, and in the right semicircle is k_R. Since the 6 electrodes and the two Hall detectors are evenly distributed on the loop circuit, the arc length between neighboring electrodes 2, 3, 4, 5 and 6 can be set to be s , and the arc length between electrodes 1 and 2 or 1 and 6 is 2s. Taking the current flowing through electrodes 1 and 2 as an example, then $L_L = 2sk_L$, $L_R = 4sk_R + 2sk_L$, $\frac{L_R}{L_L} = \frac{4sk_R+2sk_L}{2sk_L} = \frac{2k_R+k_L}{k_L}$. If the current flows through electrodes 1 and 5, then $L_L = 4sk_L + sk_R$, $L_R = 3sk_R$, $\frac{L_R}{L_L} = \frac{3sk_R}{4sk_L+sk_R} = \frac{3k_R}{4k_L+k_R}$. For the connections between any two electrodes, the L_R/L_L can be calculated by the same way.

For sample 1, since the width of the left and right semicircle is the same, both are 4.38mm, it is reasonable to take $k_L = k_R$. For sample 2, the width of the left and the right semicircle is 2.82mm and 4.38 mm respectively, so $\frac{k_L}{k_R} = \frac{4.38}{2.82} = 1.55$. The L_R/L_L of samples 1 and 2 can be calculated for various modes of connections between electrodes 1 to 6.

2.5 Measurement of superconducting transition

The temperature of superconducting transition for sample 1 was first measured. Sample 1 was installed according to Figure 3 and placed in a low temperature environment. Electrodes 2 and 6 are connected to a constant current of 20mA. The voltmeter is connected to electrodes 3 and 5 to form a four-probe measuring system. As the temperature of the sample was slowly lowered, the voltage between electrodes 3 and 5 varied, and the results are shown in Figure 4

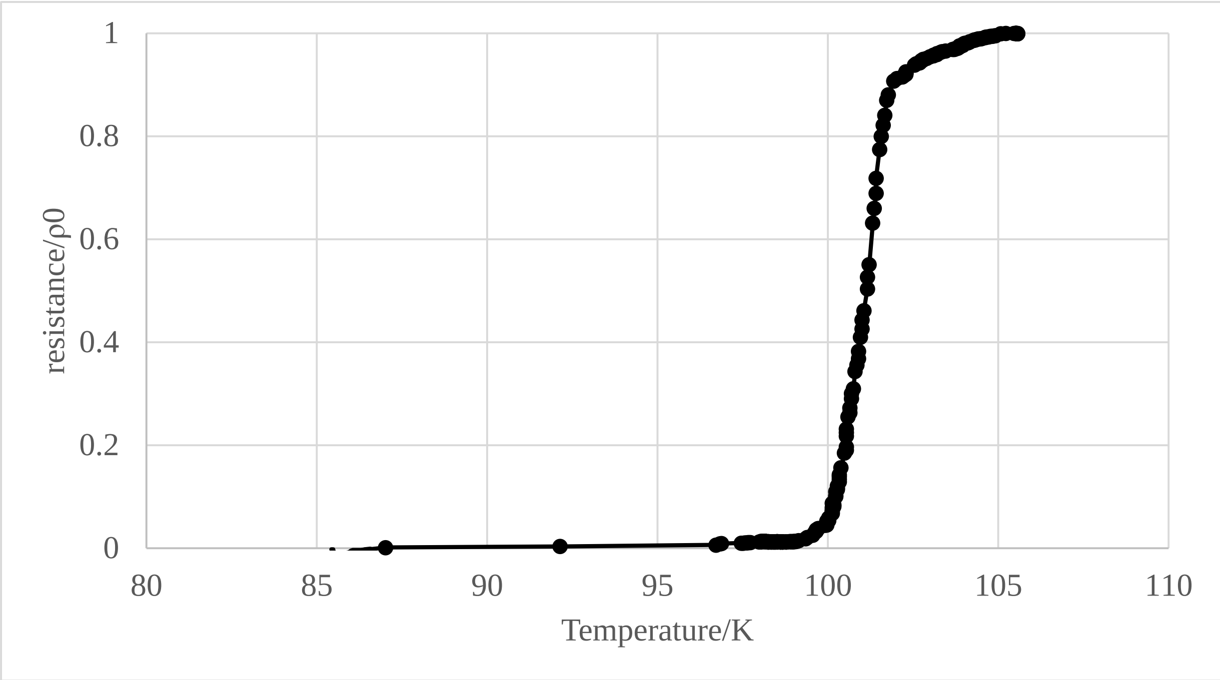

Fig.4. measurement of superconducting transition.

As can be seen from Figure 4, the superconducting transition occurs at 102 K, and is completed when the temperature is lowered to 98 K, reaching zero resistance.

2.6 The method of calibration of two Hall detectors

Let the constant current flows through electrodes 2 and 6. At this time, the same current is measured by two Hall detectors, and the measured Hall voltages can be used to calibrate the two Hall detectors. The relationship between voltages measured by two Hall detectors is established.

3 Measurements and analysis

The sample 1 was installed as in Figure 3. The temperature of the sample was lowered to 108 K. As can be seen from Figure 4, the sample is in normal state at this temperature. The constant current of 180mA is connected to electrodes 2 and 6 to calibrate the two Hall detectors.

Then, the 180mA current was connected between electrode 1 and one of any other electrodes respectively. The variation of Hall voltages was measured by changing the direction of the constant current. The measured Hall voltages are corrected by the calibration data. The ratio of Hall voltage in left semicircle to in right semicircle equal to the ratio I_L/I_R.

The above calibration and measurement process was repeated at temperature 90.5K and constant current of 100mA. The sample is in a superconducting state at 90.5K.

The result is shown in figure 5.

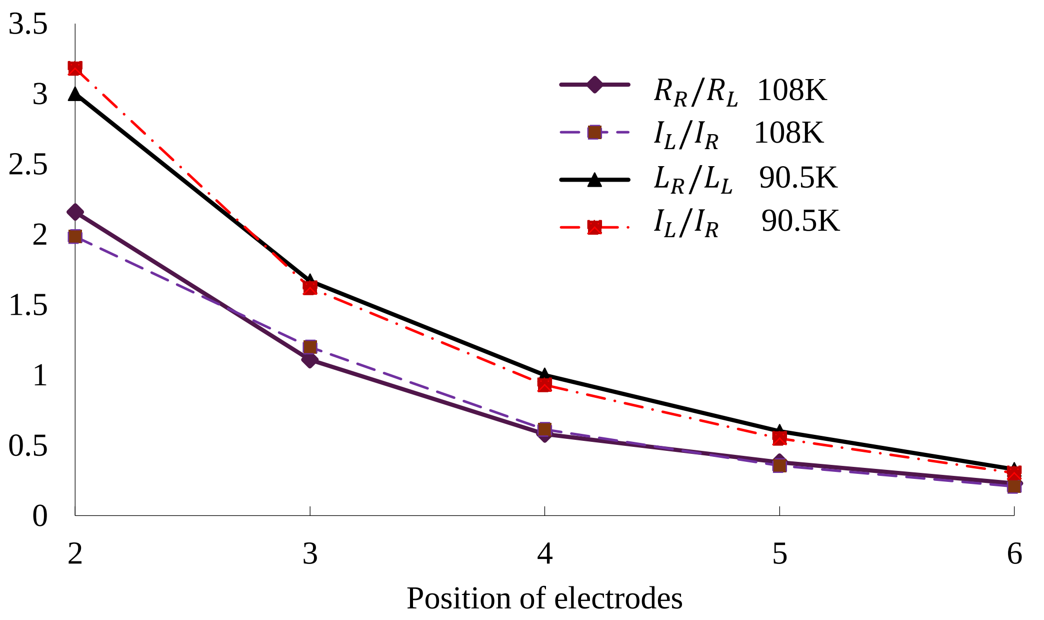

Fig. 5. The relationship of I_L/I_R (under normal state and under superconducting state), L_R/L_L and R_R/R_L with the position of electrode。 L_R/L_L and R_R/R_L (solid lines) are calculated according to the position of electrodes. Two I_L/I_R lines (dotted lines) are experimental data at temperature 108K and 90.5K respectively。

As can be seen from Figure 5, the I_L/I_R is consistent with the R_R/R_L under normal conditions. In the superconducting state, I_L/I_R coincides with L_R/L_L i.e., I_L/I_R=L_R/L_L .

The result of measurement for sample 2 is shown in figure 6

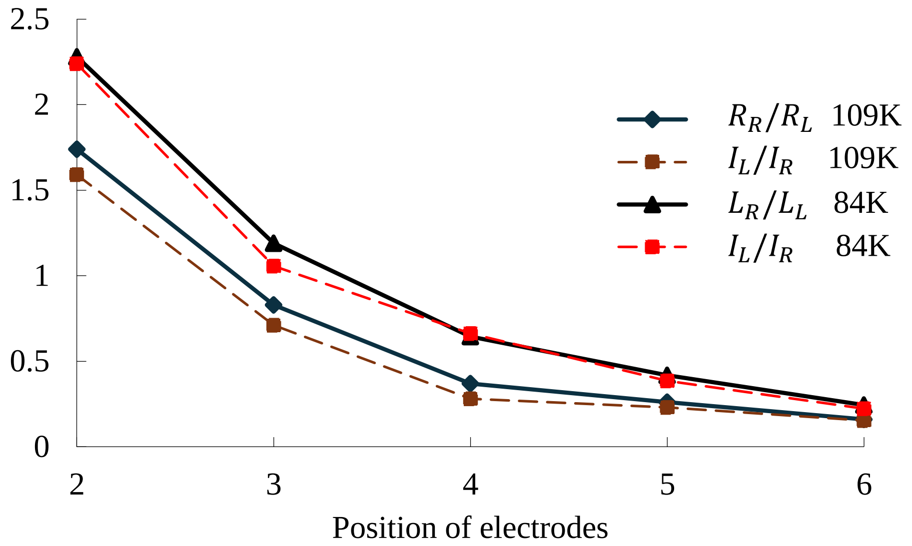

Fig. 6. the relationship of I_L/I_R , L_R/L_L and R_R/R_L with the position of electrode in the superconducting state and normal state. L_R/L_L and R_R/R_L (solid lines) are calculated according to

the position of electrodes. Two I_L/I_R lines (dotted lines) are experimental data at temperature 109K and 84K respectively.

In Figure 6, I_L/I_R is consistent with R_R/R_L under normal conditions, Under the superconducting state I_L/I_R is in agreement with the L_R/L_L,

4 Summary

In this experiment, a measurement system was designed to measure the distribution of superconducting currents in parallel circuits.

The distribution of currents under normal conditions was measured and result is agreement with the rule I_L/I_R=R_R/R_L , in accordance with the Ohm's law, it indicates that the designed measurement system is accurate and reliable.

Measurements of the two samples in the superconducting state show that the distribution of superconducting currents in the parallel circuits is proportional to the inverse ratio of their self-inductance, i.e., I_L/I_R=L_R/L_L .

In parallel circuit composed of superconductor the product of current and self-inductance IL in each branches has the role as IR in normal state analogu.e

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